

California Environmental Protection Agency



Air Resources Board

EVAPORATIVE EMISSIONS FROM OFFROAD EQUIPMENT

Engineering and Certification Branch
Monitoring and Laboratory Division

June 22, 2001

EVAPORATIVE EMISSIONS FROM OFFROAD EQUIPMENT

Introduction

This report summarizes the results of testing to quantify evaporative and permeation emissions from off-road equipment. The testing was performed to support a control measure to limit permeation and evaporative emissions from equipment that utilize small off-road engines. Test data were also generated to further develop the Air Resources Board's OFFROAD model. Testing was performed on a variety of equipment found in California's inventory of off-road equipment.

Testing Objectives

The primary objectives of the testing were as follows:

- Measure the non-fuel background emissions from new equipment
- Measure uncontrolled hot soak and diurnal evaporative emissions from handheld and non-handheld off-road equipment with summertime commercial pump fuel containing MTBE
- Measure uncontrolled hot soak and diurnal evaporative emissions from walk-behind lawn mowers with commercial fuel containing ethanol
- Measure uncontrolled diurnal evaporative emissions using a winter temperature profile
- Quantify the vented emissions arising from fuel tanks used with off-road equipment
- Quantify sources of evaporative emissions from fuel system components on walk-behind lawn mowers
- Measure uncontrolled and controlled fuel tank permeation emissions

Background Emissions

Our first objective was to determine the diurnal background evaporative emissions from new equipment at the point of sell. All of the equipment tested was manufactured at least one month prior to testing and did not contain fuel in their fuel systems.

Table 1 summarizes the non-fuel background emissions for six pieces of handheld and non-handheld equipment.

Table 1

Equipment Type	Manf.	Engine Type	Background (grams/day)
Chainsaw	Husqvarna	2 - Stroke	0.014
Walk Behind Mower	Toro	4 - Stroke	0.014
Leaf Blower	Echo	2 - Stroke	0.016
Walk Behind Mower	Murray	4 - Stroke	0.017
String Trimmer	Echo	2 - Stroke	0.017
Walk Behind Mower	Lawn Boy	4 - Stroke	0.026
Front Engine Tractor	Murray	4 - Stroke	0.066
		Average	0.024

Summertime Hot Soak and Diurnal Evaporative Emissions with Fuel Containing MTBE

Handheld Equipment

Table 2 summarizes the summertime hot soak and evaporative emissions for popular types of handheld equipment tested.

Table 2

Handheld Equipment					
Equipment Type	Manf.	Engine Type	Test Condition	Summer Diurnal Emissions (grams/day)	Summer Hot Soak Emissions (grams/ 1 hour test)
Chainsaw	Husqvarna	2 - Stroke	New	0.356	0.097
Hedge Trimmer	Echo	2 - Stroke	New	0.673	0.066
Leaf Blower	Shindaiwa	2 - Stroke	New	1.779	0.113
Leaf Blower	Stihl	2 - Stroke	New	1.500	0.163
Leaf Blower	Echo	2 - Stroke	New	1.336	0.074
			Average	1.538	0.117
			Std. Dev.	0.224	0.045
String Trimmer	Honda	4 - Stroke	New	0.715	0.071
String Trimmer	Echo	2 - Stroke	New	0.907	0.080
			Average	0.811	0.076

Handheld Equipment

Table 3 summarizes the summertime hot soak and evaporative emissions for popular types of handheld equipment tested. Data for equipment types with an asterisk were not used in the calculation of the group average or standard deviation.

Table 3

Non-Handheld Equipment					
Equipment Type	Manf.	Engine Type	Test Condition	Summer Diurnal Emissions (grams/day)	Summer Hot Soak Emissions (grams/ 1 hour test)
Lawn Mower*	MTD	4 - Stroke	Used	0.197	0.052
Lawn Mower	Lawn Boy	4 - Stroke	New	2.068	0.412
Lawn Mower	Craftsman	4 - Stroke	New	2.181	0.580
Lawn Mower	Craftsman	4 - Stroke	New	2.256	0.546
Lawn Mower	Yard Machine	4 - Stroke	New	2.289	0.406
Lawn Mower	Yard Machine	4 - Stroke	New	2.446	0.614
Lawn Mower	Yard Machine	4 - Stroke	New	2.450	0.632
Lawn Mower	Honda	4 - Stroke	New	2.495	0.475
Lawn Mower*	Toro	4 - Stroke	New	5.746	0.699
Lawn Mower*	Murray	4 - Stroke	New	8.765	2.177
			Average	2.312	0.524
			Std. Dev.	0.159	0.093
Lawn Mower	Murray	4 - Stroke	Used	4.123	0.699
Lawn Mower	Murray	4 - Stroke	Used	7.064	0.528
			Average	5.594	0.614
			Std. Dev.	2.080	0.121
Generator	Tsurumi	4 - Stroke	Used	7.392	2.358
Generator	Coleman	4 - Stroke	Used	15.045	2.721
			Average	11.219	2.540
			Std. Dev.	5.411	0.257
Front Engine Tractor	Murray	4 - Stroke	New	5.949	1.251
Rear Engine Tractor	Snapper	4 - Stroke	New	7.142	1.216
Front Engine Tractor	Toro	4 - Stroke	Used	13.015	2.093
			Average	8.702	1.520
			Std. Dev.	3.782	0.497
Edger	Honda	4 - Stroke	New	1.204	1.356
Edger	B&S	4 - Stroke	Used	1.846	0.373
			Average	1.525	0.865
			Std. Dev.	0.454	0.695
Tiller	Maxim	4 - Stroke	Used	4.123	0.571

Summertime Hot Soak and Diurnal Evaporative Emissions with Fuel Containing Ethanol

In an effort to gauge the emissions from fuel containing ethanol, hot soak and diurnal evaporative tests were repeated on five walk-behind mowers. Prior to testing, the fuel systems of the mowers were drained and refilled with fuel containing ethanol. They were then soaked for thirty days. After the soak period, the aged fuel was drained, and the mowers were filled to 50% capacity. The hot soak and diurnal tests were performed immediately after refueling. Tables 4 detail the results of the testing.

Table 4

	Commercial Pump Fuel Containing MTBE		Commercial Pump Fuel Containing Ethanol	
	Hot Soak Emissions (grams/test)	Diurnal Emissions (grams/day)	Hot Soak Emissions (grams/test)	Diurnal Emissions (grams/day)
Exhaust Emission Compliant Mowers				
Honda HRR 216	0.475	2.495		
Toro 20040	0.699	5.746	0.769	7.274
Lawn Boy 10363	0.412	2.068		
Yard Machine 11A-021C000	0.406	2.289	0.573	3.207
Yard Machine 12A-559K401	0.614	2.446		
Yard Machine 11A-089S700	0.632	2.450	1.163	3.356
Craftsman 917379440	0.580	2.181	0.858	3.266
Craftsman 917389580	0.546	2.256	0.677	3.287
Average	0.546	2.741	0.808	4.078
Std. Dev.	0.106	1.223	0.225	1.787
Average Emissions Increase			47.99%	48.81%

Wintertime Diurnal Evaporative Emissions

In an effort to measure wintertime diurnal emissions, diurnal evaporative tests were repeated on five pieces of handheld and non-handheld equipment using a winter temperature profile (attachment 2). Table 5 documents the significant reduction in evaporative emissions when using a winter profile.

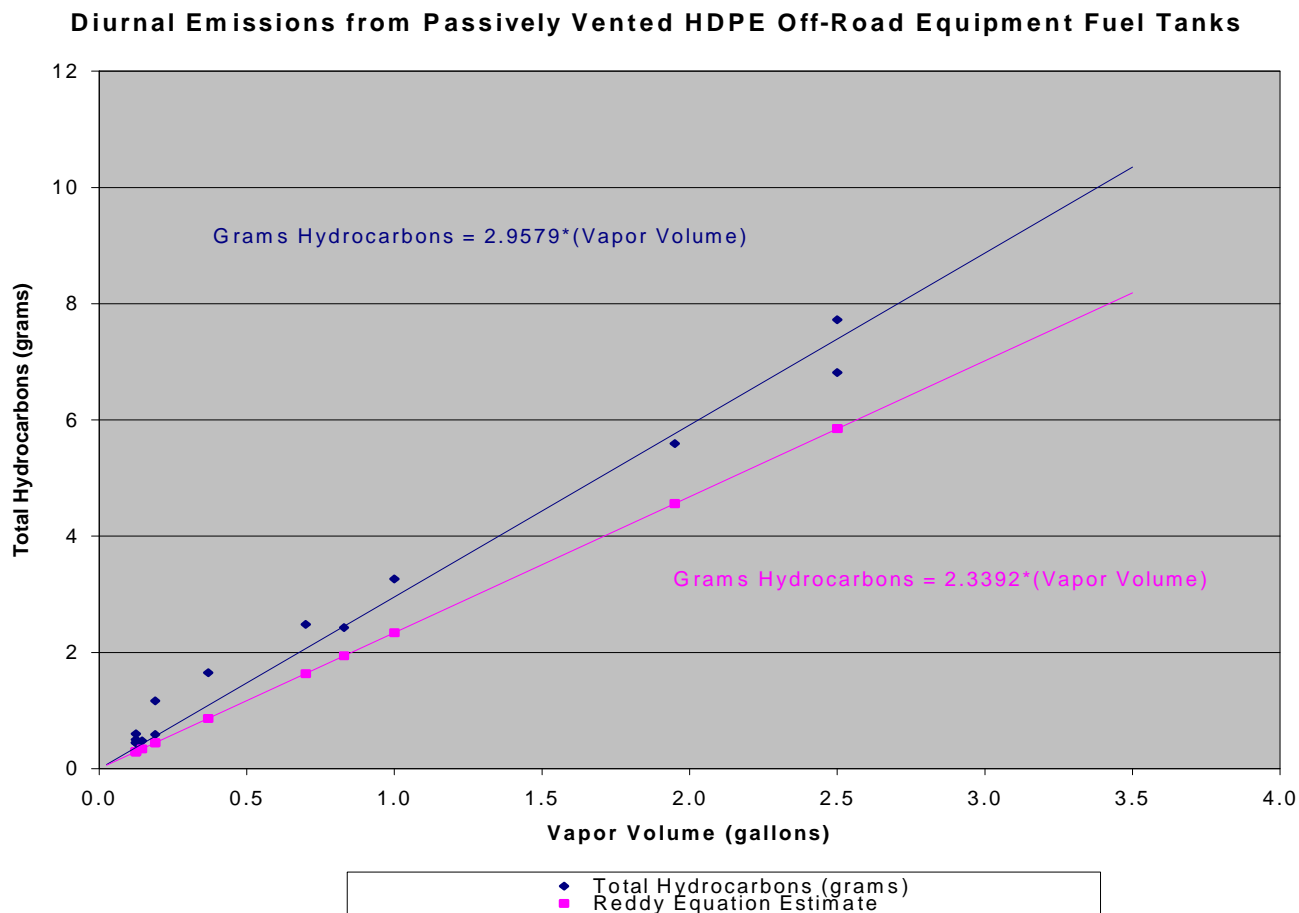
Table 5

Equipment Type	Diurnal Emissions Summer (grams/day)	Diurnal Emissions Winter (grams/day)
Coleman Generator	15.045	3.573
Murray Front Engine Tractor	5.949	2.239
Craftsman Walk Behind Mower	2.256	0.895
Shindaiwa Leaf Blower	1.779	0.526
Echo String Trimmer	0.907	0.322

Vented Emissions from SORE Fuel Tanks

In general, the vented emissions from automobile fuel tanks can be expected to follow the Reddy Equation. The Reddy equation estimates the diurnal emissions in grams for a particular vapor volume for a given rise in fuel temperature for a fuel with known Reid vapor pressure (RVP). The purpose of the fuel tank vented emission testing was to generate empirical data based on SHED testing to quantify fuel tank vented emissions. An analysis of the empirical data led us to derive a general equation for passively vented non-metallic off-road equipment fuel tanks.

The following chart compares ARB empirical data and Reddy equation estimates for fuel tank vented emissions:



The above graph suggests that large fuel tanks are a significant source of evaporative emissions. A typical 5 gallon fuel tank filled to 50% capacity can be expect to emit over 7 grams of hydrocarbons in a 24-hour summer diurnal cycle. Table 6 provides information on vented emissions from all fuel tanks tested.

Table 6

Category	Equipment Manufacturer	Model	Tank Type	Passively Vented	Tank Volume (gallons)	Vapor Volume (gallons)	Tank Vented (grams/day)
Leaf Blower	Echo	PB-231	HDPE	No	0.16	0.08	0.042
Hedge Trimmer	Echo	HC 1500	HDPE	No	0.08	0.04	0.080
Leaf Blower	Shindaiwa	EB 500	HDPE	No	0.55	0.275	0.081
String Trimmer	Honda	UMK 431	HDPE	No	0.12	0.06	0.192
String Trimmer	Echo	SRM-261	HDPE	No	0.15	0.075	0.296
Walk Behind Mower	Yard Machine	12A-559K401	HDPE	Yes	0.25	0.125	0.443
Walk Behind Mower	Craftsman	917379440	HDPE	Yes	0.25	0.125	0.443
Walk Behind Mower	Honda	HR 216	HDPE	Yes	0.29	0.145	0.477
Walk Behind Mower	Yard Machine	11A-089S700	HDPE	Yes	0.25	0.125	0.499
Walk Behind Mower	Lawn Boy	10363	HDPE	Yes	0.38	0.19	0.589
Walk Behind Mower	Yard Machine	11A-021C000	HDPE	Yes	0.25	0.125	0.596
Edger	Power Trim	208 H	Metal	Yes	0.37	0.185	1.143
Walk Behind Mower	Craftsman	917389580	HDPE	Yes	0.38	0.19	1.166
Tiller	Maxim	OO-RMT50B	HDPE	Yes	0.74	0.37	1.654
Leaf Blower	Stihl	BR 320	Nylon	No	0.38	0.19	2.171
Rear Engine Tractor	Snapper	M301019BE	HDPE	Yes	1.66	0.83	2.429
Front Engine Tractor	Murray	40508X92	HDPE	Yes	1.4	0.7	2.485
Commercial Turf	BCS	730	Nylon	Yes	2.0	1.0	3.264
Welder	Multiquip	ACX140	Metal	Yes	1.29	0.645	3.473
Front Engine Tractor	Toro	72045	HDPE	Yes	3.9	1.95	5.592
Walk Behind Mower	Toro	20040	HDPE	Yes	0.50	0.25	6.091
Commercial Turf	Toro ProLine	30177	HDPE	Yes	5.0	2.5	6.814
Tractor	Toro	3100	HDPE	No	7.5	3.75	7.262
Generator	Coleman	PowerBase 5000	HDPE	Yes	5.0	2.5	7.724

Sources of Evaporative Emissions from Walk-Behind Mowers

In order to quantify the emissions from fuel system components (carburetor, fuel line, and fuel tank), total system and separate fuel tank (vented and permeation) emissions were measured for eight walk-behind lawn mowers. The fuel tank emissions were measured using OEM replacement tanks and caps.

Fuel Tank Vented Emissions

Fuel tank vented emission tests were performed on new non-preconditioned fluorinated (controls permeation) tanks. Prior to diurnal testing, the tanks were prepped by sealing the fuel outlets with HDPE coupons, filling them to 50% capacity with commercial fuel containing MTBE, and capping them with OEM fuel caps. After prepping, each tank underwent a 24-hour diurnal test using a summer temperature profile.

Fuel Tank Permeation Emissions

Fuel tank permeation emission tests were performed on preconditioned (presoaked with fuel for 30 days) untreated tanks. After preconditioning, tanks were drained, refilled with certification fuel, and sealed with HDPE coupons in place of the OEM fuel caps. The tanks then underwent multiple 24-hour diurnal cycles in a SHED using the summer temperature profile. At the end of each diurnal cycle, each tank was weighed on a balance. When the weight loss for each tank had stabilized (standard deviation less than 0.25 grams) for five consecutive days, the average permeation rate was calculated according to ARB test method 513.

Calculated Carburetor and Fuel Line Emissions

The carburetor and fuel line contribution to total diurnal emissions was estimated by subtracting measured fuel tank vented and permeation emissions from the total diurnal emissions measured for a complete lawn mower. Additionally, separate diurnal tests were performed on three carburetors and two fuel lines to validate the calculated emissions from carburetors and fuel lines. Table 7 shows the results of testing to quantify components of diurnal emissions from walk-behind lawn mowers.

Table 7						
Mower Model	Diurnal Emissions (grams/day)	Fuel Tank Vented Emissions (grams/day)	Fuel Tank Permeation Emissions (grams/day)	Calculated Carburetor/Fuel Line Emissions (grams/day)	Carburetor Measured (grams/day)	Fuel Line Measured (grams/day)
Lawn Boy 10363	2.068	0.589	0.62	0.86		
Craftsman 917389580	2.256	1.166	0.47	0.62		
Yard Machine 11A-021C000	2.289	0.596	0.34	1.35	0.993	0.373
Yard Machine 12A-559K401	2.446	0.443	0.51	1.49	1.590	0.495
Yard Machine 11A-089S700	2.450	0.499	0.53	1.42		
Honda HRR 216	2.495	0.477	0.66	1.36	1.476	
Craftsman 917379440	2.181	0.443	0.65	1.09		
Toro 20040	*5.746	*6.091	0.74			
Average	2.312	0.602	0.57	1.17	1.353	0.434
Std. Dev.	0.159	0.063	0.128	0.33	0.317	0.086
Note: The Toro fuel tank vented emissions were suspect and not used in the calculated averages.						

Permeation Testing

Fuel tank permeation data were generated for a variety of treated and untreated handheld and non-handheld equipment. The permeation testing followed ARB test method 513 except that they did not undergo durability testing. Table 8 provides of summary of the permeation testing.

Table 8

Mfg.	Test Fuel	Fuel Density (grams/gal)	Treatment	Result (grams/gal/day)	Group Average	% Reduction Due to Treatment	% Permeation Increase Due to Ethanol
Husvarna Chainsaw	CERT Mix	2810	Untreated	1.31	0.82	100%	6%
Exmark Metro Mower	CERT	2791	Untreated	0.55			
Murray Front Engine Tractor	CERT	2791	Untreated	1.27			
Murray Front Engine Tractor	Ethanol	2828	Fluorinated	0.00			
Snapper Rear Engine Tractor	CERT	2791	Untreated	0.67		99%	
Snapper Rear Engine Tractor	Ethanol	2828	Fluorinated	0.01			
Toro Tractor	CERT	2791	Untreated	0.77			
Toro Tractor	CERT	2791	Untreated	0.88			
Toro Tractor	Ethanol	2828	Untreated	0.87			
Toro Proline Mower	CERT	2791	Untreated	0.77			
Toro Greens Mower	CERT	2791	Untreated	0.35			
Coleman Generator	CERT	2791	Untreated	0.64	99%		
Coleman Generator	Comm. Pump	2807	Fluorinated	0.00			
Echo Hedge Trimmer	CERT Mix	2810	Untreated	3.42			
Shindawia Leaf Blower	CERT Mix	2810	Untreated	2.26			
Stihl Leaf Blower	CERT Mix	2810	Untreated	0.72			
Echo Leaf Blower	CERT Mix	2804	Untreated	1.88			
Maxim Tiller	CERT	2791	Untreated	2.46			
Honda Mower	CERT	2791	Untreated	4.57			
Toro Mower	CERT	2791	Untreated	2.44			
Toro Mower	Comm. Pump	2807	Untreated	2.97			
Toro Mower	Ethanol	2828	Untreated	3.31			
Lawn Boy Mower	CERT	2791	Untreated	3.59	84%		
Lawn Boy Mower	Ethanol	2828	Fluorinated	0.56			
Lawn Boy Mower	Comm. Pump	2807	Untreated	3.25			
Yard Machine Mower	Ethanol	2828	Untreated	3.71			
B&S Quantum	CERT	2791	Untreated	5.56	5.37		
B&S Quantum	CERT	2791	Untreated	5.17			
B&S Quantum	Ethanol	2828	Untreated	5.88	5.79		
B&S Quantum	Ethanol	2828	Untreated	5.71			
Honda Trimmer	CERT	2791	Untreated	4.23			
Echo String Trimmer	CERT Mix	2804	Untreated	3.09			

Table 8 Continued

Toro Tractor	CERT	2791 Untreated	1.05		
Tecumseh Tank	CERT	2791 Untreated	2.52		
Tecumseh Tank	CERT	2791 Untreated	2.54	2.53	
Tecumseh Tank	Comm. Pump	2807 Untreated	3.38		
Tecumseh Tank	Comm. Pump	2807 Untreated	2.74	3.06	
Tecumseh Tank	Ethanol	2828 Untreated	2.94		
Tecumseh Tank	Ethanol	2828 Untreated	3.43	3.19	26%
FHP (530-049393)	CERT Mix	2804 Untreated	2.74		
FHP (530-038592)	CERT Mix	2804 Untreated	2.94		
FHP (530-038592)	Ethanol Mix	2838 Untreated	5.11		42%
FHP (530-049318)	CERT Mix	2804 Untreated	2.08		
FHP (530-049318)	Ethanol Mix	2838 Untreated	3.92		47%
FHP (530-052343)	CERT Mix	2804 Untreated	3.00		
FHP (530-052343)	Ethanol Mix	2838 Untreated	5.57		46%
Yard Machine Mower	CERT	2791 Untreated	2.74		
Yard Machine Mower	Ethanol	2828 Untreated	3.80		39%
Yard Machine Mower	CERT	2791 Untreated	4.08		
Yard Machine Mower	Ethanol	2828 Untreated	4.28		5%
Craftsman Mower	CERT	2791 Untreated	4.40		
Craftsman Mower	Ethanol	2828 Fluorinated	0.51	88%	
Craftsman Mower	Comm. Pump	2807 Untreated	5.22		
Craftsman Mower	CERT	2791 Untreated	2.32		
Craftsman Mower	Ethanol	2828 Fluorinated	1.14	51%	
Craftsman Mower	Comm. Pump	2807 Untreated	2.45		
Yard Machine Mower	Comm. Pump	2807 Untreated	4.25		
Yard Machine Mower	CERT	2791 Untreated	3.60		
Stihl Leaf Blower	CERT Mix	2804 Untreated	0.21		
Tecumseh Tank	CERT	2791 Sulfonated	2.72		
Tecumseh Tank	CERT	2791 Sulfonated	2.78		
Tecumseh Tank	CERT	2791 Sulfonated	2.71		
Tecumseh Tank	CERT	2791 Sulfonated	2.94	2.79	
B&S Quantum	CERT	2791 Sulfonated	2.94		
B&S Quantum	Ethanol	2828 Sulfonated	2.91		No Increase
Tecumseh Tank	Ethanol	2828 Sulfonated	2.90		No Reduction
Tecumseh Tank	Ethanol	2828 Sulfonated	0.71	75%	
Tecumseh Tank	Ethanol	2828 Sulfonated	2.69	4%	
Tecumseh Tank	Ethanol	2828 Sulfonated	3.71		No Reduction
Tecumseh Tank	Ethanol	2828 Sulfonated	1.50	46%	
Tecumseh Tank	Ethanol	2828 Sulfonated	0.24	91%	
Tecumseh Tank	Ethanol	2828 Sulfonated	1.99	1.96	29%

Notes:

Each row represents a unique test.

Tanks of the same model are grouped together.

Emission reductions due to treatment compares tests performed with certification fuel to tests with a treated tank.

Conclusions

The following important generalizations are based on an analysis of the above test results:

- Non-fuel related background emissions are insignificant
- Diurnal evaporative emissions are lower for handheld equipment when compared to non-handheld equipment
- Handheld equipment has significant evaporative emissions
- New walk-behind mowers typically emit between 2.1 and 2.5 grams total hydrocarbons in a summer diurnal cycle
- Evaporative emissions increase significantly (approximately 49%) when equipment is operated with fuel containing ethanol
- Wintertime diurnal emissions are significantly lower than summer emissions
- The emissions from passively vented HDPE fuel tanks follow a predictable function and are significant
- Evaporative and permeation emissions from walk-behind mowers account for roughly 50% of the total system emissions
- Fluorination is effective in reducing permeation emissions

Attachment 1

1 Day / 24 Hour / 1440 Minute Summer Variable Temperature Profile

HOUR	MINUTE	TIME REMAINING (MINUTES)	TEMPERATURE (°F)
0	0	1440	65.0
1	60	1380	66.6
2	120	1320	72.6
3	180	1260	80.3
4	240	1200	86.1
5	300	1140	90.6
6	360	1080	94.6
7	420	1020	98.1
8	480	960	101.2
9	540	900	103.4
10	600	840	104.9
11	660	780	105.0
12	720	720	104.2
13	780	660	101.1
14	840	600	95.3
15	900	540	88.8
16	960	480	84.4
17	1020	420	80.8
18	1080	360	77.8
19	1140	300	75.3
20	1200	240	72.0
21	1260	180	70.0
22	1320	120	68.2
23	1380	60	66.5
24	1440	0	65.0

Attachment 2

1 Day / 24 Hour / 1440 Minute Winter Variable Temperature Profile

HOUR	MINUTE	TIME REMAINING (MINUTES)	TEMPERATURE (°F)
0	0	1440	51.6
1	60	1380	50.5
2	120	1320	49.9
3	180	1260	49.3
4	240	1200	49.0
5	300	1140	48.7
6	360	1080	48.5
7	420	1020	49.3
8	480	960	52.8
9	540	900	58.0
10	600	840	62.5
11	660	780	65.9
12	720	720	68.2
13	780	660	69.1
14	840	600	69.5
15	900	540	69.1
16	960	480	67.2
17	1020	420	63.6
18	1080	360	59.9
19	1140	300	57.4
20	1200	240	55.9
21	1260	180	54.6
22	1320	120	53.5
23	1380	60	53.0
24	1440	0	51.6